Reviewer 2

The paper with ID “egusphere-2025-5168” investigates the impact of design hydrograph selection on key engineering parameters, including maximum outflow, required storage volume, and peak reduction. Although reservoir design traditionally emphasizes the physical configuration of the dam—such as spillway size and storage capacity—the selection of the input hydrograph remains subjective, typically guided by diverse local regulations. The results show that this choice is significant, as it directly impacts estimates for reservoir volume and safety. To reduce design errors and potential failures, the authors call for a more deliberate, evidence-based approach to selecting input hydrographs. While providing valuable practical insights, the manuscript currently contains methodological and structural issues that require revision prior to publication.

Reply: We thank the reviewer for the careful evaluation of the manuscript and for recognizing the practical relevance of the study. In response to the comments raised, the manuscript has been substantially revised to improve its scientific framing, methodological clarity, and overall readability. In accordance with the discussion-stage policy of the journal, the revised manuscript has not been uploaded at this stage, although all the modifications discussed below have already been implemented and included in the revised version to be submitted in the next phase of the review process.

A primary methodological point is the inherent bias in how the BLUE hyetograph is compared against the continuous flow time-series benchmark. The BLUE hyetograph is parameterized using the Mean Annual Maxima derived directly from the benchmark flow data. In contrast, the other tested hyetographs (Uniform, Chicago, and Variational) are derived independently from Intensity-Duration-Frequency (IDF) curves. This creates a "circularity" in the logic: the BLUE hyetograph’s superior performance is artificially inflated because it is tuned using the results it aims to replicate.

Reply: We acknowledge the reviewer’s concern regarding the potential bias associated with the BLUE hyetograph and the resulting lack of independence in the comparison with the benchmark continuous simulations.

As clarified in the revised manuscript, the BLUE hyetograph differs conceptually from the other tested hyetographs because it is not derived from IDF curve parameters. Instead, it is parameterized using statistical information associated with the mean Annual Maxima of the inflow series. Consequently, the comparison between the BLUE hyetograph and the continuous rainfall–runoff simulations is not fully independent, and the agreement observed between the two approaches may partially reflect this shared statistical basis, as specified in lines 182-186:

“This study does not adopt the previously described procedure, but considers that the maximum discharge Q of Eq. 9 equals the mean Annual Maxima of the instantaneous Qin. This

value is computed after transforming the rainfall time series into the corresponding flow time series. Therefore, this study considers that the BLUE hyetograph does not depend on the IDF parameters, but rather on the mean Annual Maxima of the instantaneous Qin. This assumption represents a methodological limitation of the comparison, and the results involving the BLUE hyetograph should therefore be interpreted with caution, as they partially reflect the shared statistical basis with the benchmark simulations"

In addition, the interpretation of the results has been revised accordingly. The performance of the BLUE hyetograph is no longer discussed as evidence of a generally superior approach, but rather as a consistency check resulting from the shared statistical basis between the BLUE formulation and the benchmark continuous simulations. We also clarify that, when complete and reliable flow time series are available, direct hydrograph-based approaches or continuous simulations remain preferable, whereas the BLUE approach may be more useful in intermediate situations where only limited flow information is available.

"Another noteworthy finding that emerged from these results is the strong performance of the BLUE hyetograph in estimating the maximum outflow discharge, which produced highly accurate results using only the peak values from the mean annual maxima inflow series. This result demonstrates that the BLUE hyetograph is particularly appealing in contexts where flow time series are available or even when only annual peak inflows are available, as it effectively bypasses the need for the IDF curve parameters or the complete time series. However, the BLUE hyetograph applicability is limited in data-scarce or ungauged regions, where rainfall or flow time series may not be available, reducing its utility in such contexts."

While the title suggests a study on hydrograph selection, the methodology is fundamentally hyetograph oriented. The analysis focuses on how four distinct rainfall patterns (design storms) are transformed into flow using standard IUH models. Because the variability in results is driven by the choice of rainfall input rather than the flow-generation mechanics, the manuscript's current framing is misleading regarding its actual scientific contribution.

Reply: We acknowledge the reviewer's observation that the proposed approach is more hyetograph-oriented than hydrograph-oriented. To better reflect this aspect, we considered revising the title to "How does the choice of rainfall-derived input hydrographs affect reservoir and dam design?", thereby emphasising the central role of rainfall input representation, particularly in the context of poorly gauged or ungauged basins.

Moreover, we revised both the Abstract and the Introduction to explicitly state that the study evaluates reservoir and dam effect in the context of rainfall–runoff modelling approaches used to derive hydrographs from rainfall inputs, particularly those based on IDF curves. Additional text has also been included to more thoroughly frame the underlying problem, emphasising the practical context in which rainfall-based methods are commonly adopted. In particular, we have highlighted that, especially during preliminary design stages, long and reliable flow time series are rarely available immediately upstream the of the point of interest, whereas rainfall information and IDF relationships are typically more accessible. For this reason, rainfall-based approaches remain widely used in engineering practice to evaluate the effects of reservoirs and dams under data-limited conditions. The abstract has been modified as follows:

"Abstract: Reservoir and dam design requires a detailed understanding of the entire input hydrograph rather than relying solely on peak discharge estimates. Input hydrographs are essential both for verification purposes to evaluate the peak attenuation capacity of the reservoir and for design purposes to define reservoir height, its volume and outlet structures. In engineering practice, particularly during preliminary design stages or in ungauged basins, long and reliable discharge records are often unavailable immediately upstream of the point of interest. Consequently, rainfall-based approaches derived from Intensity–Duration–Frequency (IDF) relationships are widely adopted to generate design hydrographs through rainfall–runoff modelling procedures, especially in poorly gauged or ungauged basins. However, no universal guidelines suggest which combination of design hyetograph and rainfall-runoff model should be used to estimate the input design hydrograph for reservoirs and dams. As a result, practitioners often rely on local regulations and heterogeneous methodologies, frequently without clear evidence regarding the advantages and limitations of different hydrograph definitions. This study investigates how sensitive reservoir and dam design is to the selection of the input hydrograph obtained from rainfall-runoff modelling by quantifying the resulting differences in key reservoir parameters, including maximum outflow discharge, maximum storage volume, and peak attenuation effects. The analysis compares the outcomes obtained using the most commonly adopted rainfall-based hydrograph generation procedures, particularly those based on rainfall time series routing and IDF-derived design events. The study highlights how different rainfall-derived hydrograph definitions can lead to substantially different reservoir routing results and design implications. The findings emphasize the importance of a more informed and consistent hydrograph selection process, especially in data-scarce environments where rainfall-based methods represent the primary source of hydrological information. In addition, the study addresses the computational challenges associated with reservoir routing analyses by discussing efficient yet reliable alternatives for defining input hydrographs in reservoir and dam design practice."

Standard dam design is built upon the evaluation of events with specific return periods (e.g., T=10,000 years). However, the authors utilize a design-event approach that is unusually independent of return periods, applying a generic growth factor instead. The paper fails to explain the practical implications of this simplification or address whether applying actual return-period scaling would alter the comparative performance and ranking of the tested hyetographs.

Reply: We acknowledge the reviewer's observation regarding the return-period-independent framework adopted in the study. The objective of the manuscript is not to perform probabilistic design estimation associated with a specific return period, but rather to compare the relative effects of different rainfall-derived hydrograph definitions on reservoir routing behaviour under consistent modelling assumptions.

For this reason, the simulations were performed assuming KT=1 corresponding to the base condition without return-period adjustments. This assumption is consistent with the objective of the study, which focuses on comparing reservoir responses under different rainfall-derived hydrograph generation procedures rather than on probabilistic design estimation. In this framework, the mean annual maximum represents a robust reference magnitude for comparing alternative modelling approaches while avoiding additional uncertainty associated with the fitting of extreme value distributions and the estimation of return-period-based quantiles, which may be sensitive to the adopted probabilistic model and sample length (Assani et al., 2006).

This approach is consistent with established methods used to characterize hydrologic regimes when the primary objective is to analyse and compare flow magnitudes rather than define regulatory design thresholds. As discussed by Assani et al. (2006), the mean of annual maxima can provide a reliable reference indicator while reducing the uncertainty associated with fitting extreme value distributions to relatively short samples, which may lead to unstable return-period estimates.

The revised manuscript now clarifies this aspect more explicitly and discusses the practical implications of the adopted simplification. In particular, we acknowledge that applying actual return-period scaling could modify the absolute values of the resulting routing parameters and potentially influence the relative performance of the tested hyetographs, especially because different rainfall durations and temporal distributions may respond differently to scaling effects. Nevertheless, the primary aim of the study was to isolate and evaluate the influence of the hyetograph definition itself, rather than to reproduce a site-specific probabilistic design procedure.

We also clarify that return-period effects can readily be incorporated within the proposed framework through the growth factor KT in Eq. (5), when required for practical engineering applications.

Assani, A. A., Stichelbout, E., Roy, A. G., & Petit, F. (2006). *Comparison of impacts of dams on the annual maximum flow characteristics in three regulated hydrologic regimes in Québec (Canada)*. Hydrological Processes, 20(16), 3485–3501.

The authors acknowledge that their findings are highly context specific. The study relies on a single reference basin, a specific rainfall station (Grazzanise), and one real-world dam (San Giovanni). This narrow geographical and climatic scope means the results may not be applicable to different catchment scales, varying upstream topographies, or diverse climatic regions, limiting the paper's broader utility for the global engineering community. Could the authors expand the analysis and in one more real case study for generalization purposes?

Reply: We acknowledge the reviewer's observation regarding the context-dependent nature of the results. The study was intentionally designed as a comparative methodological investigation aimed at evaluating the sensitivity of reservoir routing results to different rainfall-derived hydrograph definitions under consistent modelling assumptions, rather than as a universally applicable design framework. For this reason, the selected basin, rainfall station, and real-world reservoir were intended as representative test cases to investigate the methodological behaviour of the analysed approaches. We agree that different climatic conditions, catchment characteristics, hydrological regimes, and reservoir configurations could influence the quantitative results and potentially modify the relative behaviour of the tested hyetographs.

To address this limitation, the revised manuscript now more explicitly discusses the context-dependent nature of the findings and the limitations associated with the selected case studies. We also clarify that the proposed framework is fully transferable and can be applied to different catchments, climatic regions, and reservoir systems.

Regarding the inclusion of an additional real-world case study, we agree that this would further strengthen the generalization of the results. However, performing a fully consistent additional analysis would require extensive hydrological and hydraulic data collection, calibration, and validation procedures that are beyond the scope of the present study. We therefore consider this aspect an important direction for future research and explicitly mention it in the revised Conclusions section.

A flow chart of the proposed method may also be added. The authors are requested to ensure that international readers/scientists will be able to apply this methodology on their data sets by following the flow chart.

Reply: We thank the reviewer for this suggestion. In the revised version, we explicitly outlined the manuscript organization, as we believe this improves navigation and comprehension without altering the original structure of the paper. However, we will include a dedicated flow chart if the reviewer considers that this addition is still recommended. At this stage, the following text has therefore been added to the Introduction:

"The remainder of the paper is organized as follows. Section 2 presents the theoretical background, introducing the fundamental concepts of rainfall–runoff modelling and reservoir routing. Section 3 describes the methodology adopted in this study, including the derivation of rainfall inputs from IDF curves, the construction of design hyetographs, the application of IUH-based approaches to obtain the corresponding input hydrographs, and the reservoir routing procedures to obtain the output hydrographs. Section 4 presents the case studies, including both synthetic test cases and a real-world application. Section 5 reports and discusses the

results obtained for each case study, maintaining a consistent structure to facilitate comparison. Finally, Section 6 summarizes the main findings and conclusions of the study."

The introduction section would still benefit from a slightly deeper contextualization of previous comparative studies on reservoir routing to firmly establish the state-of-the-art.

Reply: The Introduction was substantially expanded to provide a clearer discussion of the state of the art and additional references to previous comparative studies on rainfall–runoff modelling, design hydrographs, and reservoir routing approaches. In the revised manuscript, we now guide the reader more explicitly from the general need to select design hydrograph for reservoirs and dams to the specific challenges associated with choosing one approach over another. The introduction has been reorganized as follows. After the first paragraph where we introduce the importance of the full design hydrograph for dam and reservoir design, we discuss the possible ways to obtain them: either directly from observed flow time series, where available, or indirectly through rainfall–runoff modelling procedures. We emphasize that, when designing new hydraulic infrastructure, it is often uncommon to have discharge observations exactly upstream of the point of interest.

"The design hydrograph for reservoirs and dams can either represent an observed flood event (Dimas et al., 2025) or a synthetic one that synthesises and preserves some physical properties and statistical information about the flow time series (Aureli et al., 2023; Mediero et al., 2010; Michailidi and Bacchi, 2017). However, most basins are ungauged, thus, flow time series are often unavailable, statistically sparse, or limited to annual peak flows, making it challenging to derive past events or construct reliable design hydrographs directly (Evangelista et al., 2023). Moreover, when designing new infrastructure is rare that there is a flow time series exactly upstream the point of interest. As a result, it is common to rely on indirect procedures to estimate design hydrographs according to rainfall-runoff models."

Then, we clarified that, among the indirect procedures to obtain the design hydrograph, the availability and reliability of hydrological information strongly influence the choice of the methodology, particularly in ungauged or poorly monitored catchments.

"The indirect procedures to estimate design hydrograph span a wide spectrum of complexity. At one end, rigorous distributed or semi-distributed hydrological models simulate the physical processes governing runoff generation and routing in the upstream basin, accounting for spatial variability in precipitation, land cover, soil properties, and topography (Montaldo et al., 2024;). At the other end, simplified lumped rainfall–runoff models aggregate catchment behaviour into a set of parameters with clear physical meaning, offering more practical implementations. The choice of modelling strategy is therefore strongly conditioned by data availability. Indeed, when detailed hydrometeorological datasets exist, more advanced process-based models can be applied; in ungauged or poorly gauged contexts, practitioners are often constrained to lumped rainfall-runoff models. Indeed, rainfall time series and Intensity Duration Frequency (IDF) curve

parameters are typically more numerous and geographically uniform than flow records, and rainfall-runoff models are usually based on a few parameters with a clear physical meaning (Cristiano et al., 2017).”

Within the framework of indirect procedures, we also expanded the literature review by citing studies that estimate design hydrographs for reservoirs and dams through rainfall–runoff approaches. In particular, we clarify that a widely adopted procedure consists of transforming a design hyetograph (or design storm) associated with a given return period into the corresponding design hydrograph through a rainfall–runoff model:

“Specifically, Cipollini et al. (2022) adopted rainfall events derived from IDF curves to quantify the impact of multiple reservoirs on flood frequency at the catchment scale. Similarly, Evangelista et al. (2023), in their analysis of the flood attenuation potential of Italian dams, justified the use of IDF-based rainfall inputs as a means of simplifying the hydro-climatological factors controlling design flood peaks while still preserving the dominant influence of rainfall characteristics on flood generation processes.”

We then explicitly introduce the core problem addressed by the manuscript: currently, no universal guidelines exist to indicate which combination of design hyetograph and rainfall–runoff model should be adopted for estimating the inflow design hydrograph for reservoirs and dams. Moreover, the simulation of reservoir routing processes for multiple possible hydrographs is computationally demanding, making a comprehensive exploration of all possible scenarios impractical. As a result, design practices are commonly based on the prescriptions of local authorities, which can differ substantially across countries and regions.

“Although numerous studies have focused on the derivation of synthetic hydrographs from rainfall data and on reservoir routing techniques, fewer contributions have explicitly examined how different rainfall-derived hydrograph definitions affect reservoir design outcomes under comparable modelling assumptions. This limitation is particularly relevant when IDF-based approaches are used as the primary source of hydrological input information.”

Finally, we now conclude the introduction by clearly stating the objective of the study. Specifically, this work investigates how sensitive reservoir and dam design is to the selection of the input design hydrograph by quantifying the resulting differences in key reservoir parameters, such as maximum outflow discharge, maximum storage volume, and peak attenuation effects. More specifically, the objective of this study is to evaluate how different rainfall-based procedures, particularly those relying on IDF-derived design events, influence reservoir routing results and key performance indicators, and to compare these outcomes with those obtained from routing a continuous flow time series.

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Additionally, there are structural inconsistencies: for example, the paper provides mathematical definitions for both free spillways and bottom outlets, yet the synthetic test cases appear to simulate only bottom outlets. This lack of clarity makes it difficult for readers to fully evaluate the robustness of the simulation framework.

Reply: Concerning the structural inconsistencies related to spillways and bottom outlets, this aspect has also been clarified in the revised manuscript. The governing routing equations were intentionally presented in a general form to maintain compatibility with both spillway and bottom outlet configurations, while the distinction between the two structures is represented through the parameters ccc and nnn, whose formulations depend on the hydraulic structure and outlet geometry.

The synthetic analyses intentionally focused mainly on bottom outlets because the objective of the study was to investigate the sensitivity of flood attenuation and peak reduction to the selected input hydrograph under consistent routing assumptions. Bottom outlets exert a stronger and more continuous influence on reservoir routing behaviour, thereby allowing a clearer comparison among different hydrograph definitions. In contrast, uncontrolled spillways generally become active only when the reservoir water level exceeds the spillway crest elevation and mainly function as safety structures to convey excess inflow once the available storage capacity is exceeded. Consequently, their influence on attenuation metrics is typically more limited and strongly dependent on spillway crest elevation and reservoir filling conditions.

The manuscript now more explicitly clarifies that the synthetic simulations were not intended to reproduce the complete operational behaviour of a real reservoir system, but rather to isolate the effects of alternative hydrograph-generation procedures while limiting additional sources of variability associated with operational rules, multiple outlet structures, and dynamic reservoir management strategies. Nevertheless, the routing framework remains fully compatible with more complex reservoir configurations. In addition, the real-world case study included in the manuscript considers a spillway-operated reservoir, and this aspect is now more clearly explained in the revised text.

For the motivations listed above, the paper in its present form needs revisions in order to evaluate the innovative character of the manuscript. However, the paper is of general interest for international audience and merits publication in HESS Journal when the major and minor comments are addressed. Addressing these comments will improve the quality of the paper and help the general reader of the paper.

Reply: We believe that these revisions substantially improved the clarity, consistency, and scientific positioning of the manuscript, and we appreciate the reviewer's comments for helping strengthen the quality of the paper.